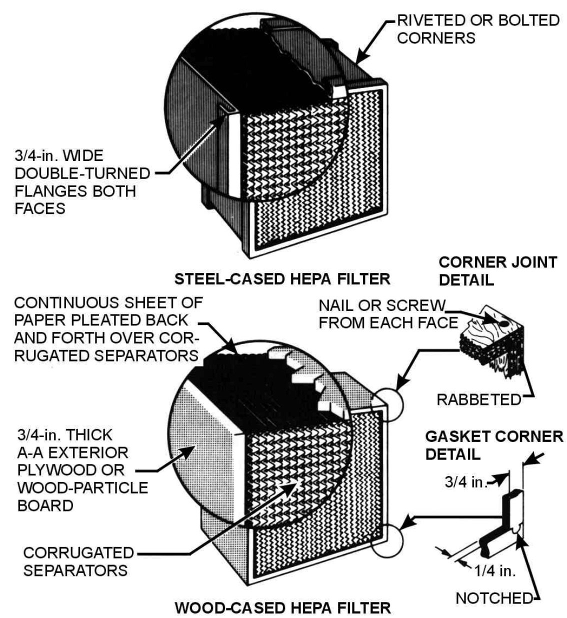

Figure 3.1 – Filter casing

Stainless steel membrane filters operate like industrial cleanable cloth filters in that they depend on a dust layer for high-efficiency particle removal and must be cleaned periodically, usually by reverse compressed air jets.

3.2 FILTRATION

The porosity of air filters has been noted. High porosity is associated with low resistance to airflow (e.g., low-resistance HVAC filters contain approximately 97 percent voids). In a uniformly dispersed filter medium, the individual fibers are relatively far apart—so far apart that the gaps between them are larger than the particles removed from the air. This means that sieving (particle removal via openings that are smaller than the particle dimensions) is not an important filtration mechanism. In fact, a sieve would make a poor air filter, even one containing submicrometer openings, because each collected particle closes up a sieve opening so that very soon no air can pass through. In contrast, real filters collect particles from air and gas streams in a number of well-defined ways that are associated with the dynamic properties of airborne particles as they respond to the physical forces present as an aerosol passes through a porous medium composed of small granules, fibers, or other shapes.

3.2.1 PARTICLE COLLECTION BY FILTERS

FIGURE 3.2 shows the streamlines around a spherical granule or a single filter fiber lying normal to the flow direction. A particle entering the flow field surrounding the fibers must follow the curved path of the streamlines before it can pass around the obstacle. When particles possess sufficient inertia, they resist following the curvature of the air stream and come in contact with the fiber because of their higher momentum relative to that of the conveying gas molecules. The effect becomes greater as both aerodynamic equivalent diameter and the velocity of the air approaching the fiber increase.

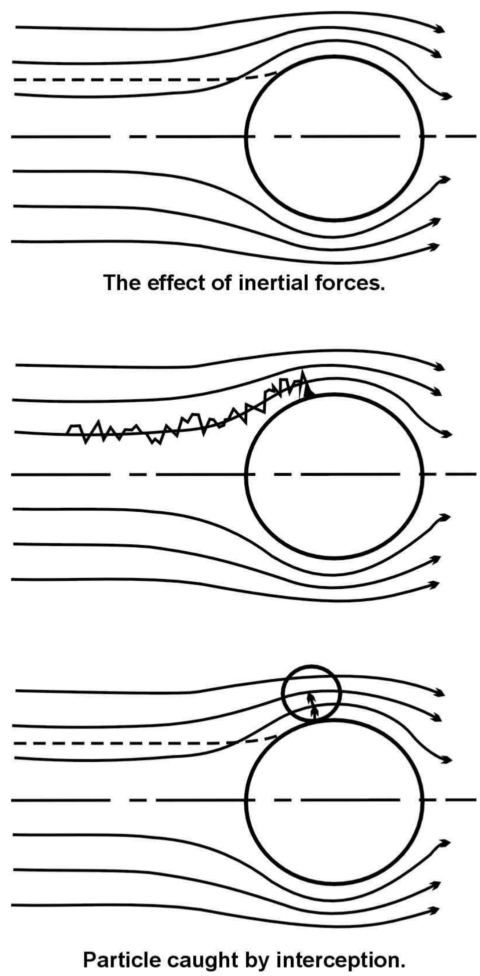

Figure 3.2 – Streamlines around a filter fiber

When suspended particles are very small, however, they tend to follow the curved streamlines closely; that is, they have little inertia, but are in vigorous Brownian motion. Therefore, when a streamline passes close to the fiber surface, the random movements around the streamline may result in some of the particles contacting the fiber and adhering to it. This sets up a concentration gradient between the zone close to the fiber and the bulk of the aerosol which, in turn, results in particle diffusion in the direction of the fiber surface. The smaller the particles, the more vigorous their Brownian motion and the more effective their filtration by diffusion. Because the rate at which small particles cross streamlines under the influence of diffusional forces is slow compared to rate of the effects of inertial force on large particles, separation of small particles by diffusion is enhanced by slower velocities through a filter.

Particle collection by interception occurs when a particle traveling in a streamline that approaches a fiber within one particle radius makes contact with the fiber and adheres to it. Interception is independent of flow velocity and is enhanced when the diameter of the collecting fiber or granule approaches the geometric diameter of the particle.

Electrostatic charge phenomena have been employed to enhance the collection efficiency of medium-efficiency filters for small particles. Naturally occurring charges on particles or filter elements are not believed to have a significant effect on the collection efficiency of HVAC or HEPA filters.

The several filtration mechanisms of importance are shown together in **FIGURE 3.3**, where penetration (equal to 100 minus collection efficiency) is plotted against particle size. The penetration curves are not cumulative, as particles can be collected but once; however, the net effect can be approximated by the solid summation curve. FIGURE 3.3 makes it clear there is a particle size where both inertial and diffusional

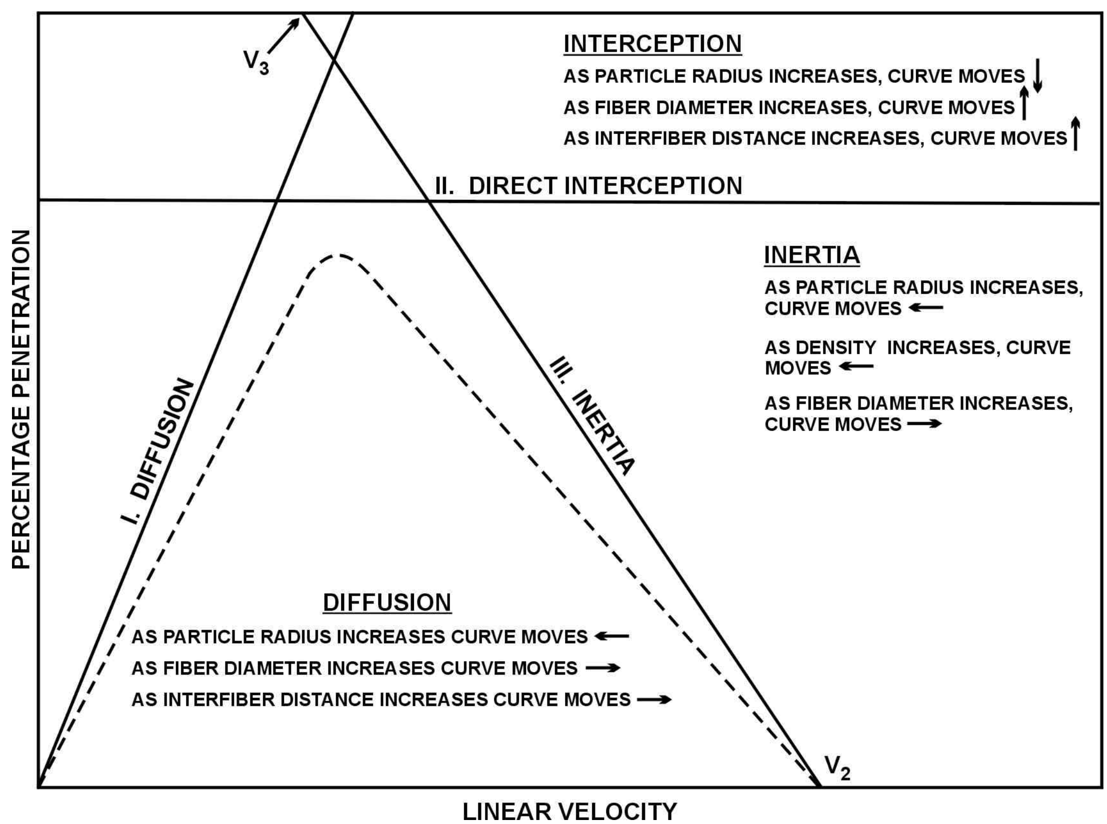

Figure 3.3 – The effects of inertia, diffusion, and interception on the penetration-velocity curve

forces are minimal and only interception is unaffected. This explains the concept of a minimum filterable particle size. The exact minimum size depends on fiber diameter, filter construction, and flow velocity. The minimum filterable particle size for currently manufactured nuclear grade HEPA filter papers is close to 0.1 µm when operated at the design flow rate of 2.5 cm/sec. The effect of flow velocity on particle penetration for HEPA filter paper also shows a minimum efficiency point.

3.2.2 Particle Retention in Filters

After an airborne particle contacts a filter element, retention forces prevent re-entrainment under the influence of the drag of the air. For small particles, the principal retentive force is a surface phenomenon called the Van der Waals force, which is proportional to the total area of contact. For small spherical particles, the fraction of the total surface area in contact with a filter fiber will be relatively large, resulting in a retention force that exceeds the re-entrainment force of the air drag. For prefilters, which are intended to remove only the largest airborne particles, a reverse relationship between retention and re-entrainment forces occurs, causing collected particles to seep through the filter under prolonged airflow unless the filter fibers are coated with viscous liquids to wet the collected particles and increase the area of contact between them and the filter surfaces. Seepage of particles collected on HEPA filters never occurs unless the filter paper becomes thoroughly wet. For this condition, different entrainment mechanisms are involved. Electrostatic charges and a thin water film hypothesized to condense from the air at the interface between the collected particles and the collector surfaces are also believed to play a role in particle adhesion, but they do not act simultaneously because the electrostatic charge dissipates in the presence of moisture, whereas little condensation occurs in dry atmospheres.

3.2.3 Airflow Resistance of Filters

Filter resistance is directly related to airflow rate and filter construction details. Decreasing the diameter of filter fibers or granules produces higher resistance for the same overall unit volume of the solid fraction of the filter medium. Greater filter depth at the same porosity increases resistance in proportion to the increase in depth. Within limits, compressing a highly porous filter medium decreases porosity and increases flow resistance, but it does not have much influence on particle removal efficiency until the medium becomes highly compressed.

The text in Section 3.2.1 that describes how fine particles are collected by filter elements applies to new, clean filters. As particles collect on the surfaces of fibers or granules, or become entrapped in the interstices between upstream elements of the filter, the collected particles tend to form a coherent dust layer known as a filter cake. When this occurs, particle collection gradually shifts from media filtration (i.e., particle removal by individual filter fibers or granules) to cake filtration, and the filter shares the characteristics of the industrial cloth filter because the original structure now has the sole function of providing support for the filter cake and the filter cake completely takes over the particle separation function. This transformation produces two important changes: (1) efficiency increases in proportion to the increase in thickness of the cake; and (2) after formation of a coherent filter cake, resistance of the filter to airflow, which initially increased at a slow, steady rate as particles accumulated, now increases at an accelerating rate in response to additional particle deposition and narrowing of the pathways. When cake filtration begins, the filter rapidly reaches its terminal design airflow resistance. **FIGURE 3.4** shows typical pressure rise curves for two HEPA filters exposed to atmospheric dust. As shown, the long, slow pressure rise is clearly followed by a rapidly accelerating increase. The reason for the abrupt change is the onset of sieving, which takes over when the collected particles form a structure containing less space between the particles than the characteristic diameter of the particles being collected. When HEPA filters and prefilters reach this stage, they must be replaced.

3.3 HEPA Filters

The original specifications for HEPA filter media and cased filters were concealed under a veil of military secrecy because of their use for chemical, biological, and radiological defense purposes. Following World War II, the Atomic Energy